

# Device-to-Device Communications and Small Cells: Enabling Spectrum Reuse for Dense Networks

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**Abstract**—In the evolution of communication networks, there has always been a need to increase the capacity to cope with the continuous growing demand for data transmission. However, with the arrival of the Internet-of-Things (IoT) and the commoditization of broadband access through smartphones, tablets, smart-watches, and all kind of connecting devices, future networks must be capable of providing not only higher bandwidth and Quality of Experience (QoE), but also, operating in dense networks with massive number of simultaneous connections. This high number of connections will be very heterogeneous, spanning from highly-demanding data rate applications to low-complexity and high energy-efficient Machine-to-Machine (M2M) communications. In such dense and complex scenario, a more flexible use of spectrum resources is deemed to be the way to meet the growing requirements for data transmission. In particular, this paper focuses on Device-to-Device (D2D) communications and small cell deployments as emerging facilitators of such demanding and heterogeneous scenario. Pros and cons of both complementary strategies are identified from both a technical and a business points of view, and main standardization activities are discussed. The aim of this paper is to identify and describe open challenges and to inspire new areas for research which turn viable the next generation of dense networks.

**Index Terms**—Spectrum Reuse; Device-to-Device; Indoor deployments; Small cells; Licensed Secondary Access; TV White Space; Energy consumption, LTE-Advanced; Machine-to-Machine Communications.

## I. INTRODUCTION

Mobile data networks have always been in continuous evolution aiming at satisfying the increasing demand for higher data rates and improved Quality of Experience (QoE). Indoor coverage has lately received particular attention due to the fact that, since 2010, around 80% of the data traffic is being generated inside houses or office buildings<sup>1</sup>. In addition, the envisioned increased number of devices adverted by the Internet-of-Things (IoT), which is expected to be two orders of magnitudes greater than the number of traditional consumer electronics, together with the commoditization of

broadband access, are shifting the future communication networks' design. However, Mobile Network Operators (MNOs) only have access to a limited section of the spectrum and they pay billions of euros to get licenses. But the traffic in mobile network is increasing so rapidly that MNOs nowadays implement data usage caps or high prices per Bytes.

This is leading research to solve issues related to efficient spectrum usage to achieve the required capacity and handling a huge variety of coexisting types of traffic patterns, spatial distributions, and density levels of users with lower investment costs [1]. Industry players (wireless operators and vendors), regulation bodies, and research institutions debate between three major options in order to overcome the capacity concerns in the long term<sup>2</sup>:

- 1) **Allocate additional spectrum resources for wireless networks.** There are undergoing studies of the feasibility to use additional dedicated licensed spectrum bands for future wireless systems. Preliminary analysis refers to the use of frequencies above 40 GHz with continuous bandwidth in the order of hundreds of MHz for high data-rate transmissions. Also, sub-GHz bands are being proposed for Machine-to-Machine (M2M) communications that transmit at very low data rates over long distances. Other options include the use of TV White Space (TVWS) or Licensed Secondary Access (LSA) to spectrum that is currently allocated to different systems, e.g., radar communications.
- 2) **Enhance spectral efficiency of radio technologies,** targeting at improved maximum data rates per unit of bandwidth. As an example, multiple-antenna techniques will become standardized components of mobile technologies like LTE-Advanced and beyond. On-going studies are focused on reducing their complexity and the associated energy-consumption to facilitate their use in consumer electronics.

<sup>1</sup>According to Cisco Systems' statistics and forecasts.

<sup>2</sup>Globecom 2012 "Industry forum" Chih-Lin I, Chief Scientist, Mobile Research Institute, China.

- 3) **Deploy denser network infrastructure and use spectrum in a more flexible manner:** capacity increase demand can be provided by means of more efficient outdoor and indoor network planning through dense deployment of smaller cells in areas that require more capacity, enabling higher frequency reuse. In addition, in highly dense networks, a flexible use of spectrum can facilitate the viability of future networks.

The first option depends on political and economical reasons which are not (directly) in reach of technicians and researchers. Related to the second option, it is worth resorting to the work done by Dohler *et al.* [2], which clearly states that the improvements attained over the last decades in research at the physical layer are negligible compared to the gains obtained from using smaller and denser cell deployments. According to Cooper's law, wireless throughput doubles every 30 months since 1957. The main constituents allowing such increase are a 1600-fold gain due to smaller cell deployments, a 25-fold increase from wider spectrum allocation and a mere 5-fold increase is due to physical layer improvements [2].

In this paper, we highlight the spectrum management options that allow a more flexible utilization of the spectrum and then we focus on two promising approaches that can benefit from the use of a fine-structure of the spectrum; *i)* enabling Device-to-Device (D2D) communications to exploit short-range transmission between devices in proximity of each other [3], and *ii)* deploying small cells, probably in combination with license-free networks such as WiFi, leading to the concept of Integrated Femtocells and Wi-Fi (IFW). We discuss pros and cons of these technologies, identify open research topics, and describe the main standardization activities being carried out. We qualitatively analyze the feasibility of integrating these techniques in current cellular networks and compare of the trade-offs in terms of energy consumption, deployment costs, backhaul implications, and scenarios feasibility of the two solutions.

The remainder of this paper is organized as follows: spectrum reuse techniques based on different kinds of “fine-structure” are described in Section 2. Then, two promising techniques that make use of this flexible use of spectrum are described. In particular, D2D communications and small cell deployments are discussed in Section III and IV, respectively. The paper is concluded in Section V.

## II. FLEXIBLE FINE-STRUCTURE SPECTRUM MANAGEMENT

The implementation of a less restrictive spectrum regulation would allow for a more effective usage of spectral bands that are today underutilized [4]. Spectrum has been traditionally regulated in two manners: exclusive-license and license-free. The reason to provide exclusive-license over the spectrum is to control interference in primary systems. Therefore, a less restrictive regulation would entail many challenges related to the co-existence of heterogeneous networks sharing the same spectrum. Such alternative solutions are based on the fact that some exclusive-license bands are under the concession of primary systems which do not necessarily always use

the spectrum. Therefore, it would be feasible for secondary systems to take advantage of such bands as long as they do not interfere with the primary system.

Flexible spectrum solutions can be split into three main groups, as discussed in the next subsections.

### A. Hierarchical Spectrum Access

A recurrent concern inherent to spectrum sharing is the challenge to prevent service disruption of primary systems. A hierarchical or multi-tier spectrum access refers to a separation in levels of priorities to access the spectrum. This approach has the potential to resolve the limitations related to unprotected systems [4] and to guarantee the coexistence of human and machine types of traffic, providing different levels of protection for each system. A multi-tier approach provides the following categories of protection:

- **Primary System:** is the system that holds full license of the spectrum and its service should never suffer from disruption. Some examples are Digital Terrestrial Television or radar systems; such systems must be interference-free but its coverage is limited to specific areas.
- **Protected Secondary System:** a “soft-license” is granted to provide protection for secondary systems against interference from other secondary systems. However, it does not provide any protection against disruptions caused by the primary system. This category could be used, for example, for time-critical M2M applications.
- **Unprotected Secondary System:** this category corresponds to systems which do not have a license to operate on the spectrum; therefore, they can only access these bands when no primary or protected secondary services are present. This category could be suitable, for example, for non-real time M2M applications.

In [4] and [5], it is explained that databases and geo-location information are required to ensure primary system protection. Secondary systems must search in the databases for authorized spaces to establish the communications when possible.

### B. Licensed Shared Access (LSA) for Outdoor Mobile Deployments

LSA corresponds to a regulatory framework allowing incumbent MNOs to partially share the spectrum. LSA licenses can be restricted in location, frequency, and time domains to avoid interference with other systems. These conditions may be static or dynamic (based on the demand on the spectrum owner). Dynamic LSA requires advanced cognitive technologies and systems to update the sharing conditions [5]. For outdoor macrocell deployment, LSA can allow MNOs to use more bandwidth (e.g., above 100 MHz). This allows providing the same capacity with less number of sites (e.g., based stations) and thus providing high data rates and capacity in a cost-efficient manner. This value of “more spectrum” will be exemplified in Section IV. Both the ETSI Technical Committee on Reconfigurable Radio Systems (RRS)<sup>3</sup> and the IEEE

<sup>3</sup>The Technical Report ETSI TR 103 113 contains a System Reference Document (SRDoc) for mobile broadband services under LDS regime, including expected usage scenarios, technical characteristics and parameters and performance requirements.

Dynamic Spectrum Access Networks Standards Committee (DySPAN-SC)<sup>4</sup> are developing standards and documentation for mobile broadband services under LSA and advanced spectrum management techniques respectively.

### C. Use of Secondary Spectrum Access for Indoor Mobile Broadband Offloading

Mobile data offloading have been widely discussed in the literature [6]. These solutions include offloading via Wi-Fi and femtocells as alternatives to alleviate congestion in dense mobile networks. While Wi-Fi can reuse the already deployed infrastructure, there are some concerns about the benefits of using unlicensed bands for offloading purposes, since they are becoming more congested and have no capability to ensure a degree of Quality of Service (QoS). In its turn, the use of femtocells reusing the licensed spectrum raise the potential thread of interfering users at the macrocell.

Despite posing severe challenges in order to ensure protection to protected users, the combination of short-range technologies to offload main cellular networks constitute a promising approach to handle the expected huge number of simultaneous connections in the near future. Therefore, such kind of approaches must deserve more attention.

In the next two sections, two emerging solutions that can benefit from a flexible management of the spectrum will be presented, namely Device-to-Device communications and Small Cells (see Figure1). Both alternatives pose new research challenges that will be discussed, as well as current standardization activities on the two topics.

### III. DEVICE-TO-DEVICE COMMUNICATIONS

Device-to-Device (D2D) communications refer to the direct transmission between end devices in proximity in the context of a cellular network [7], [8]. The spectrum used for such peer-to-peer communication can be allocated according to any of the techniques described in the previous section.

Figure 2 illustrates the three paths that can be followed to establish a connection between two devices attached to a cellular network [9]. In this example, we have used the terminology adopted by LTE to refer to the elements of the

<sup>4</sup>More specifically, the IEEE1900.6a Working Group focuses on potential databases and sensing interfaces for LSA.

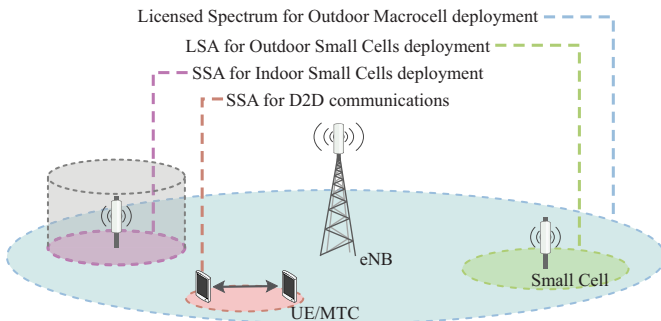


Fig. 1. Flexible Spectrum Management solutions for Dense Networks: D2D communications and Small Cells.

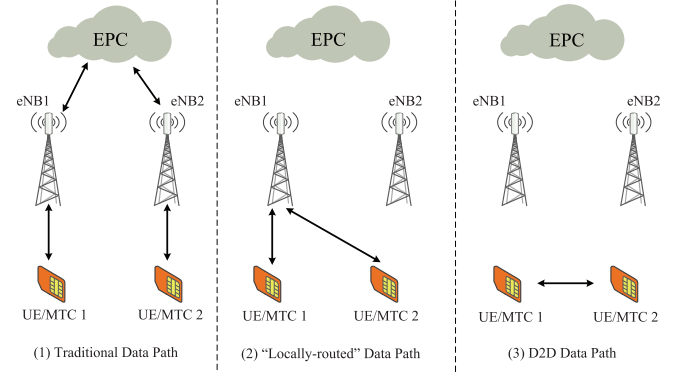


Fig. 2. Three Alternative Data Paths to Connect a Source with a Destination

network, i.e., UE for User Equipment, MTC for Machine-Type Communication device, and eNodeB for evolved NodeB (base station). The 3 alternatives to establish communications are:

- 1) **The traditional 4-hop data path:** establishing connections from the UE/MTC to the eNodeB, from the eNodeB to the Evolved Packet Core (EPC), and then down to the UE/MTC through another eNodeB.
- 2) **The locally-routed 2-hop data path:** which consists in letting the eNodeB route the traffic between two UE/MTCs without having to route traffic through the backhaul network.
- 3) **The one-hop D2D data path,** which establishes direct connection between source and destination.

The benefits of D2D communications in cellular networks are [8], [10]:

- **One-hop communication:** The use of a one-hop link translates into lower complexity (no need for routing protocols), lower delays, and higher spectrum efficiency (at least twofold and fourfold with regard to traditional and locally-routed paths, respectively).
- **Higher spectral efficiency:** transmissions though shorter distances between transmitter and receiver let attain higher data rates.
- **Spectrum reuse:** with proper radio resource allocation and interference management, D2D and cellular links can utilize the same spectrum simultaneously, thus increasing spectrum reuse factor.
- **Low transmission power:** a D2D link established between two devices within short distance can use very low transmission power, thus reducing interference to close sites, allowing higher spectrum reuse, and reducing the energy consumption of communication devices.
- **Coverage extension:** A device can establish a D2D link to act as relay between a third device and the eNodeB and thus extend coverage without new infrastructure.

Figure 3 depicts three examples where a D2D link coexists with a cellular link. The first scenario shows D2D without spectrum reuse; two D2D links use different radio resources from the cellular links (different frequency carriers), thus avoiding interference. In the second scenario D2D links share the same radio resources with the cellular link, thus reusing spectrum. Since D2D links can generate interference to the

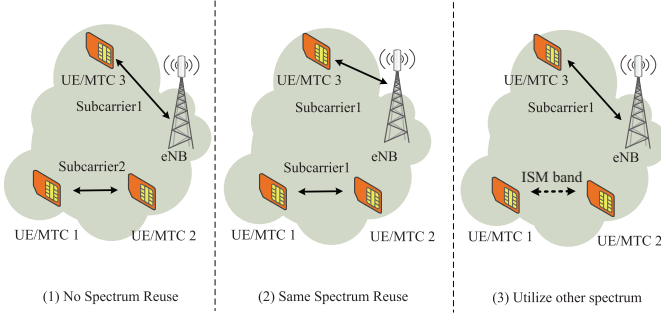


Fig. 3. D2D Communications: Enhancing Spectrum Reuse

cellular links using the same radio resources, the scheduler must define the transmit power and allocate the radio resources for the D2D links in an efficient manner such that interference does not affect communications. The third scenario shows the case where D2D links use a license-free band decoupled from the licensed-band. In this case, the D2D link does not interfere the cellular link at all. D2D communications affect the current network architecture in the following aspects:

- **User plane:** As mentioned above, D2D supports direct and local-routed data path, which are different from the traditional data path through the core network. This reduces the data traffic in the core network and its associated capacity requirements.
- **Control plane:** Signaling between D2D users can also be exchanged directly or routed by the same control base station, which reduces the signaling traffic in the core network.

#### A. Key Open Challenges

The exploitation of D2D communications in cellular networks advertises new promising ways of operating networks in a highly efficient manner and contribute to the challenge of handling dense networks. However, the use of D2D communications also engenders new challenges that must be solved [10]:

- **Peer discovery and mode selection:** it is necessary to discover suitable peers to establish D2D links in a fast and efficient manner in order to achieve an optimal balance between throughput, interference, and resource efficiency. The dynamic decision of whether using the cellular link or the D2D path remains a very challenging topic.
- **Radio resource allocation:** D2D communications can be established using either centralized or distributed resource allocation strategies. Centralized solutions may become extremely complex for large networks, while distributed solutions increase the complexity on the device side. A hybrid solution can be also envisioned, where the eNB allocates a resource pool for D2D users, which then allocate resources of the pool in a distributed manner. The design of such hybrid solutions remains an interesting topic for further research.
- **Power control:** setting the optimal transmission power to enable frequency reuse is a very complex and interesting

topic. The simultaneous use of the same frequency in a same cell using the same frequency introduces a mentality shift in the way that cellular networks are operated today.

- **Interference management:** D2D links can increase the intra-cell interference between the traditional cellular users and D2D links. D2D communications also create new types of inter-cell interference heuristics which need to be explored and further understood.
- **Security:** D2D users under the coverage of the cellular networks can directly utilize the security schemes provided by the networks. However, for the users out of the cellular coverage, such as the scenario of Public Safety Communications, a security environment cannot be established easily due to the lack of direct signaling connection to the core network. In this case, the corresponding peer user must help relay the associated security signaling. Since multiple hops can exist and the relay users may face malicious attacks, which are originally intended to the base station, designing lightweight security schemes is a crucial challenge to be addressed.

In addition, D2D communication may affect some of the network functionalities due to its unique traffic path. The Lawful Interception (LI) is such a case. LI is used by the authority to obtain the communication network data including signaling and traffic. For confidential and efficient reasons, the monitoring equipment (Law Enforcement Monitoring Facility) usually connects to the core network elements through various cables. So, the direct traffic between D2D users cannot be monitored normally. The current solution is disabling the D2D mode when LI occurs. Further research may be needed for the D2D communications without the coverage of cellular networks.

Even though current research works mainly focus on the design of scheduling algorithms to maximize system throughput, minimize energy consumption, and maximize spectral efficiency [11], the topics outlined before constitute fundamental pieces to be solved before D2D communications can become a reality in cellular networks.

#### B. Standardization Activities

D2D communications are referred by the 3GPP to as Proximity Services (ProSe) [9] in Release 12. ProSe include discovery processes to identify UEs in proximity of each other, and communication processes to establish communication between two UEs in proximity through a direct path or a locally routed path through the eNB (see Figure 2). A UE can utilize its own capabilities to discover the neighboring UEs or it can obtain this information from the backhaul network when required.

There are 3 main types of use cases studied by the 3GPP [9] which reflect the 3 main market drivers for ProSe:

- **Local commercial advertisement:** to automatically send advertisements to passing devices.
- **Network offloading:** to prevent congestion in the network by transmitting through direct links between UEs.

- **Public safety communications:** to fully support public safety communications when there is no available coverage.

In 2011, the 3GPP Technical Specification Group (TSG) Service and System Aspect (SA) started the feasibility study of ProSe and defined the technical requirements (document TR22.803) in December 2012. The technical specifications for ProSe were then written in Release 12 documents TS22.278 and TS22.115. From December 2012, The TSG SA has been studying the architecture enhancements that are required to support ProSe (Document TR23.703). The ProSe activities related to the Radio Access Network are expected to be postponed to Release 13.

As for the activities of M2M, ETSI created in 2009 a dedicated technical committee to identify key M2M use cases (TS102.935 for smart grid, TS102.898 for automotive applications and TS102.691 for smart metering), understand the service requirements (TS102.689) and promote standards for the complete end-to-end M2M functional architecture (TS102.690) and interfaces (TS102.921). Later, in 2012, the OneM2M<sup>5</sup> platform was also established by ETSI, with other international standardization bodies, to promote the deployment and success of M2M applications. 3GPP first described the MTC Service Requirements in TS22.368 based on the ETSI M2M functional architecture and interfaces. And in Release 10, 3GPP tried to improve the network system for M2M communication with enhancements on the signaling congestion and overload control. Then in release 11, 3GPP focused on the IP addressing, MTC identifiers and device triggering. Finally in the Release 12, 3GPP has been working on the small data transmission, UE power consumptions optimization, and group based features.

#### IV. SMALL CELL DEPLOYMENT

In response to the increasing subscriber demand for coverage and capacity, MNOs tend to deploy denser heterogeneous 3G and 4G networks in outdoor environments by adding more macro and small outdoor cells; the latter referring to Micro and Pico-cells. Such dense outdoor deployments are intended to cope with the required service levels but may fall short to provide the required network capacity and QoS for indoor traffic at reasonable deployment costs and power consumptions.

The value of additional spectrum in outdoor deployment and indoor deployment (using femtocells) can be estimated by the additional costs that would result if the additional spectrum is not acquired. Analysis using this so-called engineering value is presented by many researchers [12], [13]. However, the engineering value shows large variations due to the dependence on real auction prices.

Let us consider the example characterized with the parameters shown in Table I. Taking into account the mobile subscriber demand per month in Sweden (according to Swedish regulatory body, PTS) which ranges between 2 and 5 GB per month and the published forecast reports (by partners from industry such as Cisco and Ericsson) that indicate a 15 to 30-fold increase in the global mobile data traffic in

TABLE I  
SCENARIO CONSIDERATIONS

Scenario description	
Scenario	10 buildings, 5 floors each
Area	1km <sup>2</sup>
Number of Subscribers	10000
Spatial distribution	Uniform distribution
Macrocell considerations	
Number of sectors per cell	3
Average spectral efficiency <sup>a</sup>	1.7 bits/s/Hz
Femtocell considerations	
Number of sectors per cell	1
Average spectral efficiency <sup>b</sup>	2-4 bits/s/Hz

<sup>a</sup> It can be achieved by a typical LTE macrocell coverage.

<sup>b</sup> An average spectral efficiency of 2-4 bits per second per Hz are assumed due to the expected better Signal-to-Noise ratio.

TABLE II  
COST ASSUMPTIONS

Item	Cost
Femtocell (including telecom infrastructure)	1 000 €
Macrocell Site Buildout cost (with 3 transceivers)	100 000 €
Cost of additional transceivers per Macrocell Site)	5 000 €
Installation and Commissioning Cost	5% of CapEx <sup>a</sup>
Operation and Maintenance Cost	10% of CapEx <sup>a</sup>

<sup>a</sup> Capital Expenditures.

the forthcoming 5 five years, 2 levels of mobile subscribers' demand per month are considered for current and near future demand; i.e., 5 GB and 20 GB for low and high demand, respectively. Assuming the deployment and operational costs in Table II, macrocells and femtocells are compared in terms of deployment costs and spectrum utilization to satisfy the subscribers' demand as shown in Figure 4.

In the case of macrocell deployment, the same capacity can be provided with less number of sites if the amount of spectrum is bigger. In such deployment type, LSA spectrum is an ideal framework to gain additional spectrum and reduce the deployment costs. Other types of spectrum access (reviewed in Section 2) are of less interest for macrocell deployment due

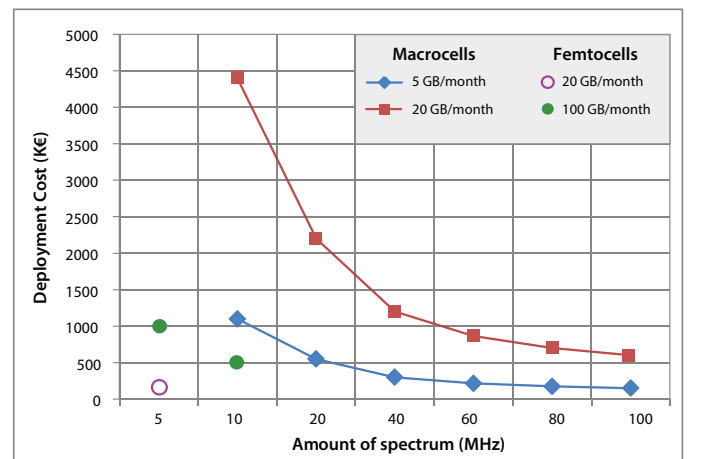


Fig. 4. Deployment cost for Macrocells and Femtocells new sites

<sup>5</sup>Organization website: <http://www.onem2m.org/>



to interference concerns.

In contract, for indoor deployment with small cells the situation is different. Indoor wireless access means short-range communication and influence of wall penetration losses. These losses are beneficial for small cell deployment, since the interference from neighbor cells can be reduced. Therefore, higher frequency bands with shorter range are of interest for such deployments. Like in the D2D case, the small coverage area of dedicated indoor nodes is the main enabler for re-using the spectrum resources. Moreover, in indoor deployment scenarios, the access to more spectrum bandwidth do not necessarily lead to less number of radio base stations, this is due to the coverage bottleneck where specific number of femtocells will be required.

Ongoing research studies focus on the deployment of both femtocells and Wi-Fi networks to offload the main cellular link, improve indoor coverage, and maintain cost and energy consumption. In fact, during the last few years, MNOs operators also use Wi-Fi networks to offload data traffic from the cellular network through agreements with the facilities owners. Working in the unlicensed ISM band have its advantages in terms of deployment cost and wide-public accessibility, but it can be a deal-breaker in dense scenarios when considering the interference coming from outer technologies that use the same band as primary services.

#### A. Key Open Challenges

There are two main challenges related to the deployment of small cells:

- **Backhaul Networks:** embracing outdoor small cells as part of a heterogeneous mobile network will drive new challenges especially in backhaul networks. Additionally, the adoption of high spectral efficiency air interfaces such as HSPA+, and LTE/LTE-Advanced increase the small cell capacity and put additional requirements on the backhaul network in terms of capacity and scalability; especially in the outdoor deployment where dedicated backhaul solution need to be deployed compared to the indoor cases. For those reasons, indoor deployment of low power base stations such as Wi-Fi and femtocell are more cost-efficient and energy-efficient solution for provisioning the required coverage and capacity in mobile network.
- **Economic and regulatory issues:** MNOs may be reluctant to use of their dedicated licensed bands for indoor deployments. However, if the same macrocells frequency band is used for femtocell deployment co-existence and interference problems may arise. Since mobile network operators may not be willing to allocate part of their licensed spectrum for dedicated femtocell deployment. Hence, there is an interest for femtocell deployment to look into alternative spectrum bands and access solutions like unlicensed, licensed shared access or dedicated licensed bands using local licenses. That is why, unlicensed spectrum resources in IMT-Bands and the Secondary Spectrum Access could be highly appealing spectrum options for indoor deployments.

Co-existing with femtocells, the ubiquitous presence of Wi-Fi coverage operating in license-free bands is stimulating infrastructure equipment vendors to integrate Wi-Fi with their small cells. In contrast to the Wi-Fi network, mobile subscribers can seamlessly move between the femtocells and outdoor cellular sites since they operate in the same frequency bands and use the same radio access technology. Moreover the network operators could have better control in the frequency planning and the provided QoS, especially when exclusive licensed band is used. Even with the enhancements brought by 802.11e amendment, Wi-Fi's QoS capabilities are still lower than those offered by the 3G femtocells. However, due to seemingly ubiquitous presence of Wi-Fi standards, infrastructure equipment vendors are now beginning to integrate Wi-Fi into their small cell and HetNet product (such as femtocells) in their portfolio strategies.

This is typically referred to as the Integrated Femto-Wi-Fi solution (IFW). By using an IFW product, it is possible to use femtocells for delay-constrained services, while throughput-demanding but delay-tolerant services can be served by the Wi-Fi radio interface. The following challenges are still to be addressed:

- **Interference management:** Studies highlight that the densification of Wi-Fi networks will lead to a negative impact on the network performance due to the lack of effective interference coordination mechanisms in an overcrowded license-free 2.4 Ghz band [14]. The licensed-free band might have its advantages related to deployment cost and accessibility, but it become challenging in terms of interference coming from other networks and other technologies using the same bands, e.g., Zigbee. The design of efficient interference management techniques is still an active area for further research.
- **Handling large number of devices:** Wi-Fi networks are based on the IEEE 802.11 Standard, which suffers from congestion when the number of devices is very high. This is due to the use of Carrier Sensing Multiple Access (CSMA) at the Medium Access Layer (MAC), which leads to very bad performance under heavy traffic loads. Therefore, the design of new ways of handling a great number of simultaneous connected devices becomes necessary.
- **Energy efficiency:** today's Wi-Fi transceivers are known to be power-hungry, in the sense that the idle listening times of this technology depletes the battery of devices very quickly. Therefore, the design and optimization of energy-efficient power modes of the IEEE 802.11 becomes necessary, such as the effort being done by the IEEE 802.11ah working group to define a dedicated standard for M2M using frequencies below 1 GHz. Companies such as Qualcomm, GainSpan, Ozmodevices, and Redpine Signals, are commercializing Low Power embodiments of Wi-Fi devices.

Assessing the true benefits of embedding Wi-Fi in femtocells is an interesting area of research.

Finally, it is worth mentioning that D2D communications and Small Cell deployments could be deployed in conjunction

to attain the best of the two options. This has been already proposed in [15].

### B. Standardization Activities

The 3GPP has a working document referred to as TR23.829 which is entitled “Local IP Access and Selected IP Traffic Offload”. This working document is under development and has the objective of allowing MNOs to offload part of the traffic from femtocells directly to the Internet, avoiding core network overload [6].

Regarding IFW, the Small Cell Forum<sup>6</sup> has been active in the definition of standard activities to integrate 3GPP and non-3GPP technologies; the document TS23.234 from 3GPP specifies the interworking between 3GPP system to Wireless Local Area Network (WLAN), defining several scenarios. Additionally, the documents TS23.327 and TS23.261 include the specification for service continuity and seamless services along the different radio access technologies, respectively. Moreover, the amendment IEEE 802.11u to the IEEE 802.11 standard adds features that enhance the interconnection with external networks, which provide a common authentication experience between 3G and Wi-Fi networks.

### V. CONCLUSIONS

The commoditization of portable connecting devices and broadband access is contributing to the continuous growth of data and QoS demand. The number of connected devices is increasing, and a dramatic increase will be witnessed once the IoT becomes a reality and common objects also get connected to the Internet. In order to cope with such growing and demanding market, MNOs and industry will have to change their business perspective and find ways to deploy and operate networks with minimum investment and maintenance costs. The flexible and dynamic use of spectrum is deemed to be one of the solutions to cope with such challenge ahead. In this paper we have discussed different approaches to access spectrum in a more flexible and granular way. Even though MNOs are still reluctant to share licensed spectrum, the huge amount of devices and the demanding data requirements will push them to find ways of using spectrum in a more agile manner. More specifically, we have identified D2D communications and small cells as true contenders to facilitate such flexible usage of spectrum. These technologies, which have received attention from international standardization bodies, are very promising to facilitate a viable coexistence of humans and machines in a very heterogeneous global connected world, but also pose some challenges that must be solved before they can actually hit the market.

### ACKNOWLEDGMENT

This work has been partially funded by Wireless@KTH research center as part of the seed project grant “M2M Communications Research Gap Study”, the Spanish research projects GEOCOM (TEC2011-27723-C02-01) and the European Commission through NEWCOM# (FP7-318306) and the Initial Training Network ADVANTAGE (FP7-607774).

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<sup>6</sup>The Small Cell Forum is a not-for-profit membership organization which aims to accelerate small cell adoption – <http://www.smallcellforum.org/>